# California Institute for Water Resources
# Annual Technical Report
# FY 2017

# Introduction

The California Institute for Water Resources (CIWR) is a special program within the University of California's (UC) Division of Agriculture and Natural Resources (ANR). The Institute is enabled by the federal Water Resources Research Act (WRRA), with the mission of supporting research and extension activities that contribute to the efficient management of California's water resources, in water quality, quantity, and reliability.

Headquartered at ANR's offices within the UC Office of the President, CIWR is well positioned to coordinate research, education, and extension activities across the 10 campuses of the UC system, as well as academic institutions across the state. Throughout California, ANR is an engine for problem solving. Serving as the bridge between local issues and the power of UC research, ANR has more than 300 campus-based specialists and county-based advisors working to bring practical, science-based answers to Californians.

CIWR brings together federal, state, and local communities to identify issues and builds support for water-related research. The CIWR mission is to provide leadership that links stakeholders with UC resources to carry out statewide water planning, research, and outreach. Given the WRRA statutory mission of education and outreach, CIWR is best suited to linking water research and extension to the needs of water managers and users throughout California. The CIWR serves an important linkage niche: science to public policy, science to education and outreach, researchers to State agencies and the public, ANR initiatives to each other, UC water centers to each other, and UC water centers to other academic institutions.

The Institute is housed within ANR to facilitate a statewide focus. The Institute also has affiliate faculty from ANR, the different UC and California State University campuses and other universities as appropriate. The CIWR Director and Academic Coordinator serve as key spokespeople on California water issues and work with federal, state, regional, nonprofit, and campus stakeholders to improve the understanding of water issues through advocacy and outreach programs. The Director also serves as Leader for ANR's Strategic Initiative on Water Quality, Quantity and Security. Thus, part of CIWRs mission is to assist ANR in the management of this Strategic Initiative. As part of that Initiative, CIWR helps to manage ANR's competitive grants portfolio. Through this partnership, CIWR is developing such strategic themes of importance as irrigation efficiency, ecosystem services, source water production and protection, water policy, drinking water, food safety, and water quality.

# Research Program Introduction

The California Institute for Water Resources (CIWR) is involved in two competitive grants programs. We manage a Request for Proposals to allocate funds from our USGS 104b program. We also assist, through the University of California Agriculture and Natural Resources (ANR) Water Strategic Initiative, with the ANR competitive grants program. USGS 104b: The CIWR receives funds from USGS that are used to support the operations of the Institute, our Information Transfer and our Competitive Grants Program. Information on outcomes from our 104b competitive grants program is provided elsewhere in this report. ANR Grants Programs: ANR invests in research, education and outreach projects that meet the goals of its mission by conducting a competitive grants program aimed to support high priority issues, encourage collaboration among ANR representatives and key players from throughout the state, support short-term high-impact projects, continue to strengthen the research-extension network, yield policy relevant outcomes, and achieve significant statewide economic, environmental and social impacts in California.

To address some of these challenges, ANR developed the Strategic Vision 2025 to identify and meet the statewide scientific, technological, social, and economic demands facing California. As an initial implementation strategy, ANR identified five Strategic Initiatives that are favorably positioned within the Division to achieve maximum results. To attest to the importance of California water research, one of the five grant categories is specifically dedicated to “Water Quality, Quantity, and Security.”

2017 Highlights Advisory committee: We continue to work with our advisory committee to administer the junior investigator competitive grants program. This year we did not have an open request for proposals as we have decided to administer our grants every two years. Strategic planning: We have been engaged in a strategic planning process for the water institute, guided by a committee of water experts from the UC system as well as state agencies and the private sector. We expect to have a finalized plan by the end of 2018.

Competitive grants program: This year we did not have an open request for proposals as we have decided to administer our grants every two years. In 2018, we will continue with the process as we have in the past, working with our advisory committee, we solicited proposals for California water related research, education, and extension projects from academics at qualified institutions statewide to be funded under the 2018 WRRA (contingent on funding). We supported several new projects on topics ranging from groundwater recharge to water conservation policy – all topics of concern in the state.

Science communication: We continue to grow an already strong web presence. Our Twitter followers number close to 8,000 composed of journalists, academics from across the country and world, non-profits, agencies, and concerned communities. We continue to work to communicate University based science to our stakeholders, with a renewed focus on highlighting the work of a diversity of researchers across the UC and CSU systems.

Nitrates in groundwater: We held an additional training for 100 California Certified Crop Advisors on nitrogen and water management, leveraging support through a project with the California Department of Food and Agriculture. The training continues to be very well received. Our annotated nutrient and water management curriculum is now also available on the web for access beyond the in-person training opportunities. We have also put together a reviewed set of publications that cover the training material in more depth – they will soon be available on our website.

Rosenberg International Water Policy Forum: The Forum brings water scholars from the around the world together on a biannual basis to collaborate on water related conflict.

# Debris flow and debris basin management impacts on water quality

## Basic Information

| | |
|---|---|
| **Title:** | Debris flow and debris basin management impacts on water quality |
| **Project Number:** | 2016CA364B |
| **Start Date:** | 3/1/2017 |
| **End Date:** | 2/28/2018 |
| **Funding Source:** | 104B |
| **Congressional District:** | 44 |
| **Research Category:** | Water Quality |
| **Focus Categories:** | Water Quality, Management and Planning, Water Use |
| **Descriptors:** | None |
| **Principal Investigators:** | Andrew Gray |

## Publications


1. Gray, Andrew. 2017. The Gray Lab: Watershed Hydrology, Geomorphology, Sedimentology, Water Quality. http://andrewgray.ucr.edu/
2. Leeper, Robert J; Barth, Nicolas C, Gray, Andrew B. December 15, 2016. Analyzing the occurrence of debris flows and floods in a small watershed two years after a wildfire, San Gabriel Mountains, California. Abstract H43G-1550. 2016 Fall Meeting, AGU, San Francisco, CA.
3. Guilinger JJ, Gray AB, Barth N, Ajami H, Leeper R. 2018. Using UAVs to characterize hillslope erosional responses in a burned catchment. UC Riverside GIS Day. Riverside, CA.
4. Guilinger JJ, Gray AB, Barth N. 2018. Characterizing post-wildfire erosion in a steep headwater catchment using nested scales topographic change detection. First Annual SoCal Geomorphology Symposium. CalTech, Pasadena, CA.
5. Jumps NI, Gray AB, Barth N. 2018. An investigation into dominant post-wildfire erosion regimes using fallout radionuclides (Cs-137 and Pb-210). First Annual SoCal Geomorphology Symposium. CalTech, Pasadena, CA.

**Final Report for California Institute for Water Resources Project Support**

**Debris flow and debris basin management impacts on water quality**,

PI: Andrew Gray, Department of Environmental Sciences, andrew.gray@ucr.edu, (951) 827-6159.

1. **Overall project summary/statement:** *1) Context and importance of the project*: This study investigates the impacts of debris flows on water quality in southern California by focusing on two recently burned headwater catchments along the southern urban/wildland interface of the San Gabrielle Mountains and one in the Box Springs Mountains. Debris flows are fast moving masses of solids and water that occur when steep terrain cloaked in unstable sediments are exposed to high intensity rainfall. Expansion of urban populations and infrastructure in southern California has progressed beyond surrounding mountainous fronts, exposing large populations to the direct hazards of debris flows and their concomitant impacts on water quality.
*2) Research and outreach during the reporting period*: A third study watershed in the Box Springs Mountains was instrumented to monitor rainfall and sediment transport, and sampled to characterize sediment composition during this period. Additional sediment samples and monitoring was conducted in the previously instrumented study watersheds along the southern San Gabrielle front. These data are being used to investigate how the interactions of atmospheric, wildfire and hydrologic events result in the triggering and propagation of debris flows, and to examine the impacts of these phenomena on downstream water quality (Fig. 1). High resolution (mm to cm scale) 3-dimensional surveys of subbasins and channel reaches were performed using terrestrial laser scanner as well as unmanned aerial vehicle (UAV) and structure for motion technology to directly examine erosional processes. Hillslope, colluvial, channel, debris basin and outlet channel sediment and water samples were collected to investigate sediment composition and redistribution dynamics.
*3) Project outcomes, impacts, and benefits to date*: Preliminary findings on debris flow production include a) the identification of increasing rainfall intensity-duration (R I-D) thresholds over time, b) discovery of fine-scale storm features related to R I-D, c) evidence for dominant hillslope erosional processes, and d) characterization of changes the composition of sediment redistributed in and exported from burned watersheds over time.

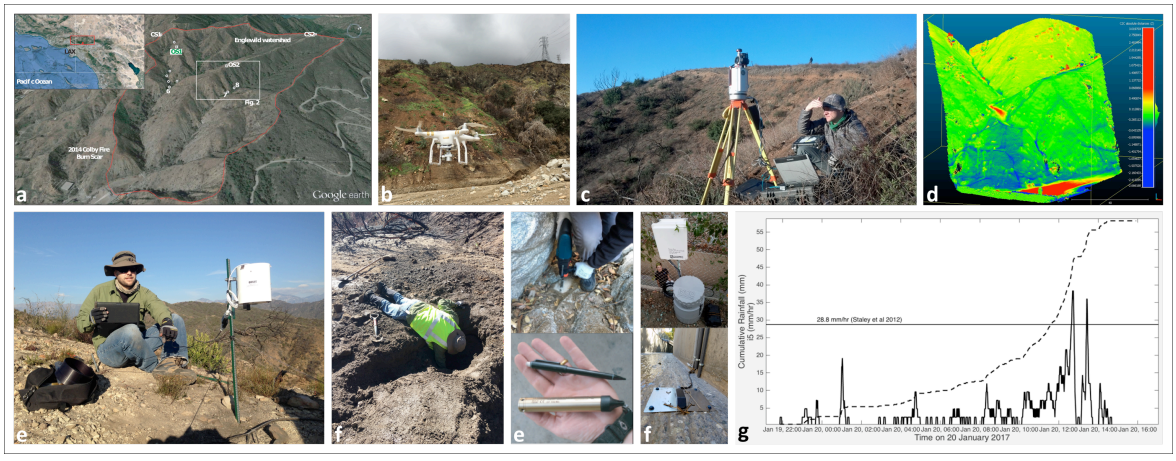


**Figure 1.** (a) Englewild Canyon field site, (b-d) 3-D surveying and DEM development, (e-g) hydro-meteorological monitoring and sediment sampling (images from R. Leeper, N. Barth and A. Gray).

**Research program:** Little is known about the quality and quantity of sediments exported from burned areas instrumented with debris basins. The research plan to approach this knowledge gap

was to employ integrating hydro-meteorological monitoring of debris flow events with debris basin operations and suspended sediment monitoring to develop a better understanding of the changing conditions required to initiate debris flows with system rebound after wildfire, and to characterize the effects of debris flows on sediment mediated water quality. Research was conducted in the watersheds of the Englewild and Las Lomas canyons: steep headwater catchments situated above the cities of Glendora and Duarte, CA that experienced the Colby (1/2014) and Fish (6/2016) wildfires, respectively. In August, 2017 a 400 ha fire burned a large portion of the western slopes of the Box Springs Moutains adjacent to the UCR campus. At 15 ha headwater catchment located in this burn area was added to our study in September, 2018 (Fig 2a).

To examine the timing and intensity of precipitation events required to trigger debris flows, both study regions were instrumented with multiple high-resolution rain gauges and self-contained pressure transducers installed in bedrock channel beds. The Englewild debris basin drainage channel was outfitted with a hydrologic gauging and sampling station to monitor water and sediment export from the basin, which included instrumentation to measure stage, average flow velocity, turbidity, and an automated water sampler. Gauging and sampling from the Las Lomas debris basin drainage pipe was not possible due to access issues. The Box Springs catchment was outfitted with pressure transducers and a time lapsed camera to record channelized flow events, as well as multiple high resolution rain gages and soil moisture sensors. Subbasins of all three catchments were surveyed at high resolution ($10^{-1}$ to $10^{1}$ cm scale) using TLS and UAV technologies. In the Box Springs catchment subsection of the TLS scan areas were outfitted with silt fences to capture eroded sediments (Fig. 2b). Resurveying in the Las Lomas study area was performed after each significant (i.e. debris flow triggering) storm. Hillslope, channel and exported sediments were characterized for particle size distribution, carbon content, and fallout radionuclide ($^{210}$Pb, $^{137}$Cs, and $^{7}$Be) abundance.

Very little debris flow activity was observed in Englewild Canyon during water years 2016 and 2017, despite five minute duration rainfall intensities surpassing know post-fire debris flow initiation thresholds (Leeper et al., 2016). In contrast, the more recently burned Las Lomas catchment produced debris flows at even lower thresholds than previously established. Evidence from these portions of the study will be used to modify existing approaches to assessing debris flow risk potential in post-wildfire scenarios. Also as a result of system rebound, including breakdown of hydrophobic layers and increased vegetative effects, the Englewild Debris Basin drainage channel experienced only very low flow levels and minor episodes of sediment transport during water year 2017. In contrast, during the wet season directly after the Box Springs fire, our study catchment produced appreciable sediment or water export due to relatively little precipitation and low rainfall intensities. Las Lomas and Englewild and Box Springs surveying and sediment sampling results are in process, but show promising indications of new evidence to support the identification of dominant erosional regimes in these landscapes, and how they shift after wildfires.

Initial sediment composition analyses indicate that debris flow deposits are highly enriched in fallout radionuclides (Jumps et al., 2018). This suggests that surficial erosion processes such as sheetwash and rill erosion are responsible for much of sediment delivery that results in debris flows. Initial findings from high resolution topographic surveying show that our TLS methods can be used to accurately detect down to 1.5 cm of elevation change (Guilinger, 2018). Initial high resolution change detection in the Box Springs suggests that rill erosion may be an important component of the erosion regime during the kind of low magnitude, high frequency rainfall events that primarily produce internal redistribution of sediment rather than sediment discharge from the catchment (Fig. 2c).

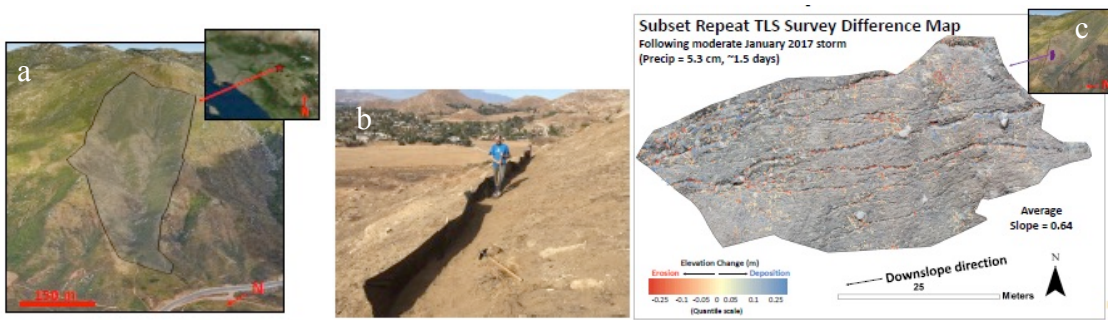


Figure 2. (a) Box Springs study catchment, (b) silt fence installation, (c) preliminary TLS change detection results. Note erosion concentrated in rills. (images from J. Guilinger).

2. **Information transfer/outreach program:** Preliminary results of this study have been communicated at the American Geophysical Union 2016 Fall Meeting (Leeper et al., 2016), at the UCR GIS Day Symposium (Guillinger et al., 2018a); at the 1st Annual SoCal Geomorphology Symposium (Guillinger et al., 2018b; Jumps et al., 2018), on the PI's website (Gray, 2018), and through coverage of our work by the UC ANR water sciences blog. Four journal articles are currently in preparation.

**Supplemental Images**

Sediment deposit excavation in the Las Lomas debris basin after the first flush following the 2017 Fish Fire in the Southern San Gabrielle front, CA. (image A. Gray).

Graduate student Robert Leeper downloads rainfall data with the Las Lomas debris basin below. (image: A. Gray)

Debris flow deposit in Las Lomas Canyon following the first rainfall events of the 2017 water year (image: A. Gray).

Scenes from direct aftermath of the 400 ha Box Springs Mountains wildfire in August, 2017.

Graduate student James Guilinger conducting TLS operations in the Box Springs burn area before the first rains hit in December, 2017. (image: A. Gray).

Graduate student Nathan Jumps revisiting Englewild Canyon to collect additional sediment samples for fallout radionuclide analyses April, 2018. (image: A. Gray).

# The Influence of Incubation Temperature on Aerobic Swimming Performance of Juvenile Salmonids

## Basic Information

| | |
|---|---|
| **Title:** | The Influence of Incubation Temperature on Aerobic Swimming Performance of Juvenile Salmonids |
| **Project Number:** | 2016CA365B |
| **Start Date:** | 3/1/2017 |
| **End Date:** | 2/28/2018 |
| **Funding Source:** | 104B |
| **Congressional District:** | 44 |
| **Research Category:** | Biological Sciences |
| **Focus Categories:** | Climatological Processes, Hydrology, Water Use |
| **Descriptors:** | None |
| **Principal Investigators:** | Amanda I Banet |

## Publications

1. One master's thesis in progress.
2. Balfour, Nicholas, Carlos Estrada, Rebecca Pilakowski, Dylan Stompe, and Amanda Banet, 2018, Impact of increased incubation temperature and thermal stress on the aerobic scope and thermal tolerance of juvenile rainbow trout (Oncorhynchus mykiss), CSU Chico College of Natural Sciences Poster Symposium, Chico, CA.
3. Balfour, Nicholas, Carlos Estrada, Rebecca Pilakowski, Dylan Stompe, and Amanda Banet, 2018, Impact of increased incubation temperature and thermal stress on the aerobic scope and thermal tolerance of juvenile rainbow trout (Oncorhynchus mykiss), American Fisheries Society Cal-Neva Conference, San Luis Obispo, CA.
4. Estrada, Carlos, Nicholas Balfour, and Amanda Banet, 2017, Impact of increased incubation temperature on the thermal tolerance of juvenile rainbow trout (Oncorhynchus mykiss), The National Diversity in STEM Conference (SACNAS), Reno, NV.
5. Banet, Amanda, February 24, 2018, What is it like to be a fish biologist? American Association of University Women Career Trek (Outreach event for 8th grade girls)

# The Influence of Incubation Temperature on Aerobic Swimming Performance of Juvenile Salmonids

*Principal Investigator: Amanda I. Banet*
*Student Researchers: Nicholas Balfour, Dylan Stompe, Carlos Estrada, and Rebecca Pilakowski*

## Project Summary

Salmonid populations in California have rapidly declined in the past century, in large part due to dams and water diversions that block critical habitat and increase water temperatures in remaining habitat. Recent work shows that salmonids exposed to high temperatures during incubation have decreased thermal tolerance later in life. Thermal tolerance has been linked to an organism's ability to deliver oxygen to its cells. Based on this, we hypothesized that fish exposed to high temperatures early in development would exhibit reduced aerobic performance later in life, as compared to fish incubated lower temperatures. We also hypothesized that this difference would be magnified when fish were swimming in high temperature waters. Aerobic performance is an ecologically relevant metric because it determines how much energy an organism can devote to activities related to survival and reproduction, such as foraging, growth, migration, and predator avoidance. To test our hypotheses, we incubated *Oncorhynchus mykiss* (Rainbow trout) eggs at three different temperatures. After hatch, we measured swimming metabolism at a range of swimming trial temperatures. We found that contrary to expectations, incubation temperature did not have a significant effect on thermal tolerance or aerobic performance of juvenile *O. mykiss* at the range of temperatures examined in this study. Student researchers are currently completing a similar study using *O. tshawytscha* (Chinook salmon), which is scheduled for completion in summer 2018.

## Research Program

*Background*

Habitat degradation and the onset of climate change are introducing organisms to novel environmental conditions that they have not historically experienced. The ability of an organism to respond to these changes determines the persistence and success of a population in the future. In California, populations of salmonids have dramatically declined over the past century, with the greatest decrease occurring since the construction of major dams and water diversions in 20$^{th}$ century. These dams have blocked critical habitat for salmonids, and have led to altered water characteristics in the remaining habit, including increases in water temperature. We know that increases in water temperature are tied to mortality and reduced reproductive success in these fish, but there is still much unknown about their capacity to deal with temperature stress on both an individual level and on a population level.

Some plasticity has been documented in salmonid life histories, meaning that they can exhibit different characteristics depending on the environmental conditions that they experience. In some cases plasticity can be adaptive, allowing an organism to immediately respond to environmental conditions, unlike genetic changes that occur at the population level on a slower generational time scale. However, one recent study has indicated that while Pacific salmon do exhibit plasticity in response to high temperatures during egg incubation, this plasticity is maladaptive. Rather than inducing physical changes that increased their ability to function in high temperature environments, fish that were exposed to high temperatures early in development had lower thermal tolerances later in life. Another body of research has suggested that thermal tolerance is a function of an organism's ability to successfully deliver oxygen to its cells. Based on this, we hypothesized that the aerobic capacity be reduced in fish that were exposed to high incubation temperatures, and that this difference would be magnified if the fish were swimming in high temperature waters. Reduced aerobic performance can be harmful to an organism because it reduces

the amount of energy an organism can devote to activities related to survival and reproduction, such as foraging, growth, migration, and escaping from predators.

This research examines the thermal tolerance and swimming metabolism of *Oncorhynchus mykiss* (rainbow trout) and *Oncorhynchus tshawytscha* (Chinook salmon) that were incubated at a range of temperatures. First we tested whether the relationship between incubation temperature and thermal tolerance in our fish was similar to that observed in studies of closely related species. We then examined whether fish incubated at high temperatures had a lower aerobic scope than those incubated at low temperatures, and whether this difference was magnified when swimming at warmer temperatures. Methods and results for *O. mykiss* are reported here. Trials with *O. tshawytscha* are ongoing.

*Methods*

We collected fertilized *O. mykiss* eggs from the Mt Shasta hatchery and transported them to the California State University, Chico salmon facility for incubation. Eggs were incubated at 10, 12.8, and 15.6°C. After button-up, juvenile fish were transferred to 10°C holding tanks. When fish were approximately three months old, their critical thermal maximum (CTmax) was tested by slowly increasing the water temperature until the fish lost equilibrium. Oxygen consumption ($MO_2$) was measured on a different subset of fish using a Loligo Systems mini-swim respirometer (www.loligosystems.com). For each swimming trial, a fish was introduced to the working section of the respirometer and allowed to acclimate overnight at a low water speed. After the acclimation period, resting oxygen consumption ($MO_{2rest}$) was measured. Subsequently, fish were exposed to progressive incremental increases in swimming speed until they fatigued. Maximum oxygen consumption ($MO_{2max}$) was estimated using the highest $MO_2$ measured during the swimming trial. Aerobic scope of the individual was calculated as ($MO_{2max}$ - $MO_{2rest}$). Each fish was tested at a range of temperatures between 10 and 15.6°C in order to examine the interaction between incubation temperature and aerobic performance across a range of temperatures after hatch.

*Results*

1. Survival to button-up was marginally higher in the low incubation temperature treatment (10°C = 92.4%, 12.8°C = 89.3 %, 15.6°C = 89.2%)
2. Incubation temperature did not significantly influence thermal tolerance (CTmax) after hatching (Figure 1A, one-way ANOVA: $F_{2,57} = 0.846$, $p=0.435$, $\eta 2=0.029$)
3. Fish mass had a small, but significant positive relationship with CTmax (Figure 1B, Linear Regression: $F_{1,58} = 4.158$, $p=0.046$, $R^2=0.067$)

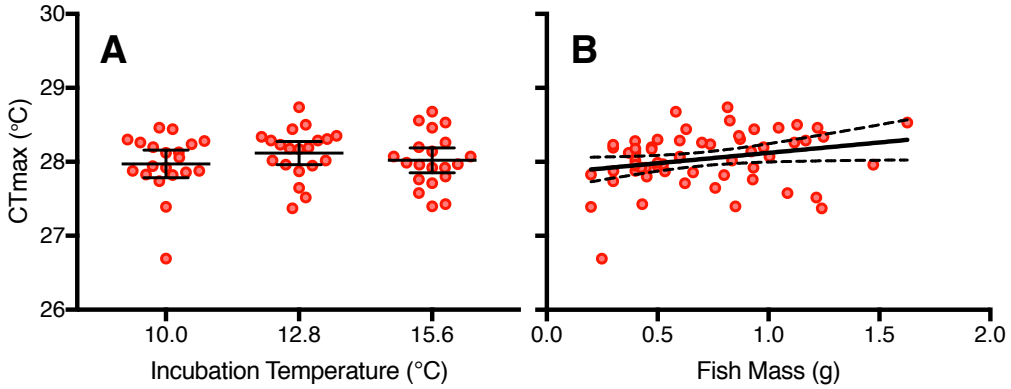


***Figure 1. Thermal tolerance (CT max) was not affected by incubation temperature (A), but it did have a small, significant positive relationship with fish mass (B).***

4. Within the temperatures examined in this study, incubation temperature did not significantly affect $MO_{2rest}$ (slopes: $F_{2,16} = 0.7174$, p=0.5031; elevations/intercepts $F_{2,18} = 2.773$, p=0.0892 ), $MO_{2max}$ (slopes: $F_{2,16} = 0.1847$, p=0.8331; elevations/intercepts $F_{2,18} = 1.796$, p=0.1944), or aerobic scope (slopes: $F_{2,16} = 0.04551$, p=0.9556; elevations/intercepts $F_{2,18} = 0.2907$, p=0.7512) of juvenile *O. mykiss* after hatching. Because of this, incubation temperature treatment groups were pooled to examine the effect of aerobic trial temperature.
5. Within the temperatures examined in this study, $MO_{2rest}$ and $MO_{2max}$ increased as aerobic trial temperature increased (Figures 2A & 2B, Linear Regressions. $MO_{2rest}$: $F_{1,20} = 8.565$, p=0.0083, $R^2$=0.2999; $MO_{2max}$: $F_{1,20} = 5.578$, p=0.0284, $R^2$=0.2181 ). Aerobic scope was not significantly influenced by temperature (Figure 2C, Linear Regression: $F_{1,20} = 0.9265$, p=0.3473, $R^2$=0.04427).

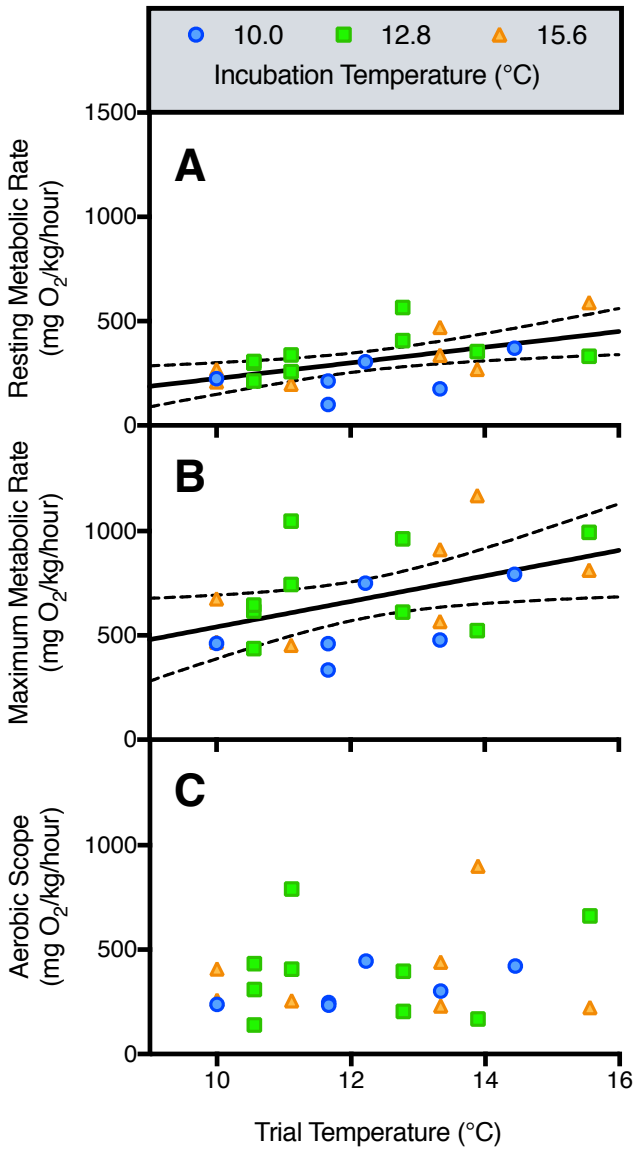


***Figure 2. Resting and maximum metabolic rates increased with aerobic trial temperature (A & B), but aerobic scope was not affected by aerobic trial temperature. Incubation temperature did not have a significant effect on any aerobic performance metric.***

*Discussion*

Contrary to expectations, incubation temperature had no effect on thermal tolerance or aerobic performance of the *O. mykiss* in our study. One possible explanation for this is that the effect of incubation temperature could vary between different salmonid species, populations, and latitudes. In addition, due to logistic constraints associated with obtaining eggs from the hatchery, our thermal treatments did not begin immediately at fertilization. Therefore, these fish may have already passed a critical point when they might be sensitive to higher temperatures. Our continuing research with *O. tshawytscha* will be able to address this, because eggs were fertilized on site and underwent four incubation treatments: high temperature, low temperature, high then low temperature, and low then high temperature. This study provides insight into the physiological effects of temperature on juvenile salmon, which can be used to help inform water management decisions.

# Can habitat restoration mediate predator-prey interactions to increase juvenile salmon survival in California's central valley?

## Basic Information

| | |
|---|---|
| **Title:** | Can habitat restoration mediate predator-prey interactions to increase juvenile salmon survival in California's central valley? |
| **Project Number:** | 2017CA369B |
| **Start Date:** | 3/1/2017 |
| **End Date:** | 2/28/2018 |
| **Funding Source:** | 104B |
| **Congressional District:** | 44 |
| **Research Category:** | Ground-water Flow and Transport |
| **Focus Categories:** | Water Use, Hydrology, Agriculture |
| **Descriptors:** | None |
| **Principal Investigators:** | Eric Palkovacs |

## Publications


1. Sabal, Megan C., Joseph E. Merz, Eric P. Palkovacs, In Review, Predation risk influences migration speed differently for wild and hatchery salmon. Proceedings of the Royal Society B.
2. Sabal, Megan C. 2018. Ready, set, go! Racing salmon to learn about migration and predator avoidance. Coastal Sustainability Guest Blog. Available at http://kristy-kroeker.squarespace.com/new-blog/2018/1/24/ready-set-go-racing-salmon-to-learn-about-migratio
3. Sabal, Megan C. 2017. How to Scare a Salmon? YouTube video available at https://www.youtube.com/watch?v=uB7d7J0PqoQ

**Progress Report for California Institute for Water Resources Project Support**

**Can habitat restoration mediate predator-prey interactions to increase juvenile salmon survival in California's central valley? PI: Eric Palkovacs**

1. **Overall project summary/statement:** California salmon populations are in decline and are threatened by nonnative predators, habitat alterations, and water management. This project examines fine-scale behavioral interactions between these three stressors. In spring 2018, we completed a field experiment to first test if salmon migration behavior changed in response to predation risk. We executed a behavioral assay in the field where we timed juvenile salmon swimming downstream with and without predator cues present. We also observed if these behavioral responses were context dependent on salmon origin (hatchery vs. wild), migratory stage (rearing vs. migrating), and physical attributes (size, condition, smoltification). Our experiment was successful, and we learned that wild salmon slowed down when faced with predator cues, while hatchery salmon did not react. Furthermore, wild salmon that were already actively migrating downstream reacted more strongly to the predator cues compared to wild salmon that were still rearing upstream. These results are extremely exciting because they suggest that not only do predators affect the survival of migrating salmon, but they also may affect the migratory behavior of salmon! Changes to migration speed can then have additional consequences on salmon survival in subsequent life stages and through indirect pathways. Additionally, our work suggests that hatchery and wild salmon are behaviorally distinct in how they react to predator cues. This could relate to different survival among groups and supports other studies which suggest predator conditioning in hatcheries may improve survival via behavior. Finally, salmon smoltification (as measured by gill ATPase activity) related to speed overall. The results from this project have already been analyzed and written up, and a manuscript was submitted to the journal *Proceedings B* on March 8th, 2018! We also presented this work at two conferences, in a guest blog post, and via an educational video.

M. Sabal in the field running behavior experiments

M. Sabal presenting at AFS CalNeva conference

2. **Research program:**

Problem: Many juvenile salmon die while they migrate from freshwater to marine environments. Mortality comes from a variety of stressors including nonnative predators, habitat alterations, and water management. Understanding how these stressors interact to shape behavioral decisions in migrating juvenile salmon is important in understanding the mechanisms that ultimately lead to mortality.

Objectives: In spring 2018, we tested whether salmon migration speed changed in the presence of predator cues and determined how responses varied by salmon origin (hatchery vs. wild), migration life stage (rearing vs. migrating), and physical traits (size, condition, ATPase activity).

Methods: We timed juvenile Chinook salmon (*Oncorhynchus tshawytscha*) swimming downstream in a flume with and without predator cues present. The flume was 2.1 m long and 0.45 m in diameter, which

we placed in the Mokelumne River. It was bisected by three PIT tag antennas, which detected the tagged salmon as it swam through. Each individual salmon was run twice—with and without predator cues present. Predator cues were provided by a plastic largemouth bass with associated odor cues. Both wild and hatchery salmon were used in the experiment. Nested within wild salmon, were salmon that were still rearing on the floodplain upstream (wild-rearing), and salmon that were actively migrating downstream (wild-migrating).

Results:

- Wild salmon slowed when faced with predator cues, while hatchery salmon did not change their speed (Fig. 1).
- Wild-migrating salmon reacted more strongly to the predator cues compared to wild-rearing salmon (Fig. 1).
- Wild-migrating salmon were fastest, followed by wild-rearing, and hatchery salmon (Fig. 1).
- Salmon with elevated ATPase activity swam slower through the flume.
- Salmon with higher body conditions swam faster through the flume.

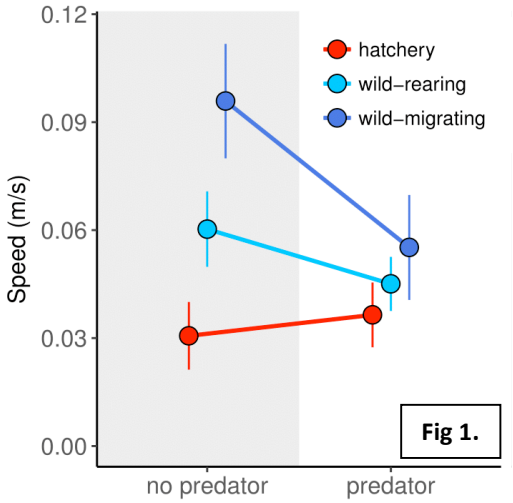

**Fig 1.**

Significance: These results suggest that predators can affect migratory behavior in salmon in addition to survival. In turn, this could have consequences on fitness of salmon at subsequent life stages. Both hatchery and salmon contribute to managed populations, therefore it is important to understand how they may behave differently.

**3. Information transfer/outreach program:**

- American Society of Naturalists Meeting, 5-9 January 2018, oral presentation
- SWFSC, NMFS, Data theory seminar, 20 February 2018, oral presentation
- American Fisheries Society, CalNeva Chapter Meeting, 1-2 March 2018, oral presentation*
- Guest Blog on UCSC Coastal Sustainability Blog
- Create educational video published on YouTube

# Fish habitat response to streamflow augmentation in support of salmon recovery in the Russian River Basin

## Basic Information

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|---|---|
| **Title:** | Fish habitat response to streamflow augmentation in support of salmon recovery in the Russian River Basin |
| **Project Number:** | 2017CA370B |
| **Start Date:** | 3/1/2017 |
| **End Date:** | 2/28/2018 |
| **Funding Source:** | 104B |
| **Congressional District:** | 44 |
| **Research Category:** | Water Quality |
| **Focus Categories:** | Hydrology, Ecology, Groundwater |
| **Descriptors:** | None |
| **Principal Investigators:** | Theodore Grantham |

## Publication

1. Rossi, Gabe, Weston Slaughter, and Theodore Grantham, 2018, “A study of aquatic habitat and fish behavior in a Russian River Tributary” in Proceedings of the 36th Annual Salmonid Restoration Conference, April 11-14, 2018, Fortuna, CA, pg 23, available at: https://www.calsalmon.org/sites/default/files/SRF_2018_Proceedings.pdf

**Progress Report for California Institute for Water Resources Project Support**

**Fish habitat response to streamflow augmentation in support of salmon recovery in the Russian River Basin (Dr. Theodore Grantham)**

1. **Overall project summary/statement:** We evaluated the ecological benefits of a Sonoma County, CA streamflow augmentation project, in which stored water was released into a stream to sustain habitat conditions for endangered salmon. We implemented a before-after-control-impact (BACI) to evaluate how stream flow, water depths, water quality, and fish behavior responded to different rates of water releases from the augmentation system. The field study was implemented between June and September 2017. We found that flow augmentation increased the length and duration of stream connectivity and had a beneficial effect on water depths and fish behavior. Flow augmentation did not have a strong effect on water quality in the first month of the study, but improved water quality in the last month of the study. The flow treatments definitively prevented the mortality of endangered fish trapped in isolated pools that would have dried up in the late summer season. Findings of the study are being used to develop an operations plan which will establish recommendations for the timing and rate of flow releases in future years. Study findings were shared with the landowner (Gallo, Inc.) and regional conservation partners at a one-day meeting in Santa Rosa. The study was also presented at the annual meeting of the Salmonid Restoration Federation.

2. **Research program:** This research project evaluated the ecological benefits of an innovative streamflow augmentation project, in which stored water was released into a stream to protect endangered salmon during the low-flow summer season. The study quantified how increased flows affect fish habitat conditions relative to an upstream control reach on Porter Creek, a tributary to the Russian River in Sonoma County, California. Using a before-after-control-impact (BACI) experimental design, we assessed how flow releases affected the hydrologic connectivity, spatial distribution, quality, and total availability of suitable fish habitat. We also quantified how effects of flow augmentation changed over the course of the dry season, when water inputs from upstream surface- and ground-water sources naturally declined. Data was collected using standard stream habitat measurement techniques at regular intervals throughout the summer season before and after flow releases and at different flow-release rates. The study was designed to test the following hypotheses:

   H1: Flow augmentation will enhance and maintain hydrologic connectivity within treatment reaches relative to control reaches.
   H2: Effects of flow augmentation on habitat connectivity, quantity, and suitability will decrease with increasing distance from release point.
   H3: The effects of flow augmentation will decrease over time during the dry season, as the contribution of natural, ambient water sources declines.
   H4: Flow augmentation will delay or prevent the occurrence of critically low dissolved oxygen levels.

   We confirmed that flow augmentation had a beneficial effect on salmon habitat. Flows released from the augmentation increased and maintained hydrologic connectivity (i.e., continuous surface water flow) for a longer duration that the upstream control reach (H1). We found that the effects of flow augmentation did attenuate with distance from the augmentation site (H2), but localized geomorphic factors (e.g., bedrock outcrops and gravel deposits) mediated the effects of flow augmentation within the treatment reach. Flow augmentation had a significant positive effect on

stream connectivity throughout the study period, although the lowest section of the treatment reach became dry in early July and remained so to the end of the study period, regardless of the flow release rates. Therefore, H3 was not supported, although it is possible that the positive effects of flow augmentation would have been diminished in a drier year, when less ambient water is available. We found that there was no difference in water quality parameters, including dissolved oxygen (DO), between the treatment and control reaches in the first part of the study, but as the dry season progressed, DO in all pools began decline and the flow augmentation stabilized or improved DO levels in the treatment reach, supporting H4.

3. **Information transfer/outreach program:** Findings of the study were shared with the landowner (Gallo, Inc.) and regional conservation partners at a one-day meeting in Santa Rosa, California. The study was also presented at the annual meeting of the Salmonid Restoration Federation. Results from the study will be used to develop an operations plan which will establish recommendations for the timing and rate of flow releases in future years.

# Optical and Thermal Remote Sensing of Turfgrass Response to Different Deficit Irrigation Strategies in Central and Southern CA

## Basic Information

| | |
|---|---|
| **Title:** | Optical and Thermal Remote Sensing of Turfgrass Response to Different Deficit Irrigation Strategies in Central and Southern CA |
| **Project Number:** | 2017CA371B |
| **Start Date:** | 3/1/2017 |
| **End Date:** | 2/28/2018 |
| **Funding Source:** | 104B |
| **Congressional District:** | 44 |
| **Research Category:** | Climate and Hydrologic Processes |
| **Focus Categories:** | Irrigation, Water Use, Water Supply |
| **Descriptors:** | None |
| **Principal Investigators:** | Amir Haghverdi |

## Publication

1. Haghverdi, Amir; Somayeh, Ghodsi., (2017), Developing Urban Irrigation Water Conservation Strategies Using Smart Soil Moisture Sensor-Based Controllers, “ASA, CSSA, and SSSA Annual Meeting”. ASA, CSSA, and SSSA. Tampa, FL (oral presentation), abstract available on line at: https://scisoc.confex.com/crops/2017am/webprogram/Paper107651.html.

*Optical and Thermal Remote Sensing of Turfgrass Response to Different Deficit Irrigation Strategies in Central and Southern CA*

**Investigators:** PI: Amir Haghverdi, Co-PIs: Maggie Reiter, Janet Hartin, Alireza Pourreza

## 2. Overall project summary/statement:

The recent five-year drought coupled with water distribution issues and the increasing urban population throughout California underscore the high priority of efficient irrigation in California metropolitan areas. As the drought conditions persist and water continues to become less available, the development of methods to reduce water inputs is extremely important. An urban feature for potential water conservation is the turfgrass landscape since is a large component of urbanized land area. Two turfgrass research trials (a total of 108 research plots) were established to bermudagrass and tall fescue turfgrass species in Riverside and in Parlier in 2017. In Riverside, a total of twelve irrigation scenarios were implemented (6 irrigation levels from 100 to 50 % reference evapotranspiration ($ET_{ref}$) and two watering days: 5 days versus 3 days a week) automatically using a weather based smart irrigation controller. We used remote sensing data to detect and measure drought injury and evaluate turf's response to the irrigation scenarios. The preliminary results showed that with adequate management of weather based smart irrigation controllers it is possible to auto adjust the irrigation level with an accepted accuracy (on average only 12 % overwatering was observed by the smart irrigation controllers) and practice water conservation strategies. Bermudagrass (a warm season turf species) showed acceptable quality for deficit irrigation treatments as low as 60% (and in some cases even 50%) $ET_{ref}$, but for tall fescue (a cool season species) severe drought injury was evident for irrigation treatments lower than 70% $ET_{ref}$. The cellphone attached thermal cameras only showed reliable canopy temperature data when multiple readings were taken and averaged per plot. We plan to collect and examine thermal images throughout the second year of the study and compare the thermal images against irrigation application and turf quality data.

## 3. Research program

The US west is generally arid and subject to droughts, yet some of the largest cities across the nation are in this region. Irrigation demand is usually the largest component of total outdoor water use in urban sectors in southern California. Therefore, improving irrigation water use efficiency of urban landscapes is crucial for maintaining urban green infrastructure while conserving water resources. The main objectives of this study were to develop water conservation strategies for irrigated turfgrass in southern California, and to quantify the impact of different deficit irrigation regimes on turf health and quality using remote sensing technologies.

A total of 108 turfgrass research plots were organized into two irrigation research trials in 2017 (Fig 1). Each plot is irrigated by 4 quarter-circle (pop-up heads) sprinklers, all four controlled by a common solenoid valve allowing independent irrigation control for each individual plot. To eliminate plot edge effect and avoid interference between adjacent plots, adequate boarders (2-3 feet) was considered and measurements were taken at the center of each plot. The uniformity, and application rate of irrigating systems were evaluated following the standard protocol (ANSI/ASABE S626). A Weathermatic Smartline SL 4800 smart ET-based irrigation controller connected to a SLW5 wireless weather sensor (Telsco Industries, Inc, Garland, TX, USA) was used to schedule irrigation at both sites. Plots were sodded with tall fescue (cool season species) and bermudagrass (warm season species) June 8, 2017 and July 27, 2017 at AES and KARE,


**Fig 1.** Research plots in two locations: (a) University of California, Riverside Agricultural Experiment Station (AES) in Riverside [a total of 72 research plots] and (b) UCANR Kearney Research & Extension Center (KARE) in Parlier [a total of 36 research plots].

respectively. These species were selected because there were available in sod form allowing faster plot establishment and root development. In addition, bermudagrass was selected due to its superior resistance to drought compared to other commonly planted turfgrasses in California. At AES, irrigation trial was started on July 9, 2017 and terminated on October 3, 2017. Two irrigation frequencies (3 days and 5 days per week) and six irrigation levels (100 %, 90 %, 80 %, 70 %, 60 %, and 50 % $ET_{ref}$) were tested. At KARE, given the time required for establishment of the plots after sodding, we realized that plots were not ready for water stress hence we decided not to impose any irrigation treatment in 2017 and have kept all plots under full irrigation treatment.

Throughout the irrigation trial, NDVI data (Fig 2) were collected from all AES plots approximately once per week (a total of 12 readings) to assess the turf's response to the irrigation scenarios and evaluate drought injury. Bermudagrass had a good performance for almost all irrigation treatments and even lowest irrigation treatment (50 % $ET_{ref}$) did not substantially impacted the turf quality. For the cool season turf, 50% and 60% $ET_{ref}$ levels treatments caused severe drought injury and leaf firing resulting in unexpected turf qualities. The 70% $ET_{ref}$ treatment performed well till mid-August but as the experiment progressed and ET demand peaked tall fescue started to show some drought injury symptoms hence was not considered as a viable treatment in pack ET months in inland southern California region. The two watering cycles (3 days versus 5 days per week) seemed to have no significant impact on turf quality, except that for the tall fescue plots under high deficit irrigation levels (i.e. 50, 60 and 70 % $ET_{ref}$) the drought injury occurred later during the experiment for the 5 days per week treatments compared to the 3 days per week treatments. One reason for this observation could be the relatively shallow root system of turf and higher water application of water for the 3 days per week cycle which probably caused some percent of the applied water to deeply percolate below turf effective root zone. There was on average 12% over irrigation relative to the desired irrigation level by the smart irrigation controller when data compared to CIMIS station nearby the experimental site. Overall, the smart irrigation controller was able to automatically adjust the irrigation run time based on the irrigation level desired. Throughout the experimental period we used two cellphone attached thermal cameras (FLIR 1 and Seek thermal) to collect thermal data and checked their performances against an accurate handheld thermometer. We observed substantial fluctuations and variations in the point thermal data collected using both cameras. However, when we used averaged readings per plot there was a good agreement between thermal data collected using thermal cameras and the thermometer.

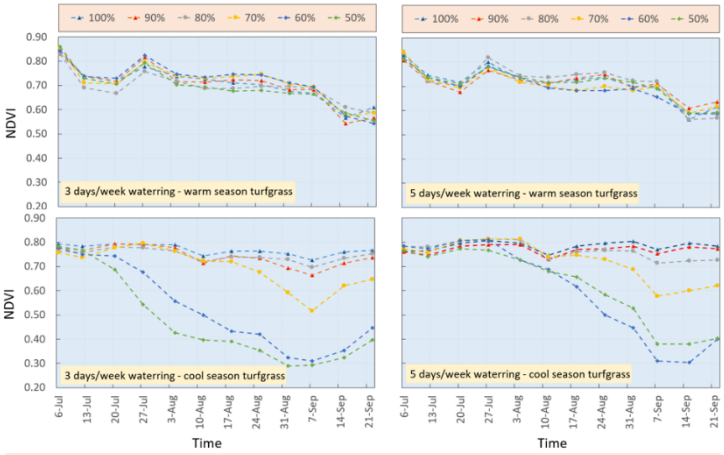



**Fig 2.** Impact of different deficit irrigation scenarios on warm season and cool season turfgrass species using remote sensing Normalized difference vegetation index (NDVI) data.

## 4. Information transfer/outreach program

The preliminary results of this study were disseminated among a diverse body of clientele through two oral extension presentations in Southern California in Orange County (9th annual Urban Landscape and Garden Education Expo) and Coachella Valley (CV Water Counts Academy on Desert Water Agency). We disseminated information about turfgrass irrigation best management practices using smart irrigation controllers and discussed water saving achieved using efficient deficit irrigation strategies. We also presented the results of this work to the scientific community and among peers at tri-societies annual meeting and WERA1022 Multistate Research Project's Annual Meeting.

# Evaluating Water Conservation Policy in California

## Basic Information

| | |
|---|---|
| **Title:** | Evaluating Water Conservation Policy in California |
| **Project Number:** | 2017CA373B |
| **Start Date:** | 3/1/2017 |
| **End Date:** | 2/28/2018 |
| **Funding Source:** | 104B |
| **Congressional District:** | 44 |
| **Research Category:** | Climate and Hydrologic Processes |
| **Focus Categories:** | Water Use, Management and Planning, Conservation |
| **Descriptors:** | None |
| **Principal Investigators:** | Leah Stokes |

## Publications

1. Leah Stokes & Patrick Hunnicutt; Presented by Leah Stokes at the Environmental Politics and Governance Conference at the School of Public and Environmental Affairs at Indiana University. Friday June 23 2017. “Evaluating Water Conservation Policy in California"
2. Leah Stokes & Patrick Hunnicutt; Presented by Leah Stokes at ETH Zurich. Thursday May 24, 2018 (scheduled). “Evaluating Water Conservation Policy in California.”

**Progress Report for California Institute for Water Resources Project Support**

**Evaluating Water Conservation Policy in California**

Principal Investigator: Leah Stokes, Department of Political Science, UCSB, stokes@polsci.ucsb.edu

**1. Overall project summary/statement:** What explains variation in California's urban water districts' ability to conserve water? In this project, I am evaluating the effectiveness of a number of conservation strategies: pricing, messaging and penalties. First, we might expect that increasing the cost of water or providing subsidies for long-term changes, like replacing lawns or appliances, might decrease consumption. In this project, I examine various pricing strategies, from cost increases to rebates. Second, significant research suggests that simple information messaging may fail to change behavior, while social norms messaging can be very effective. In this project, I examine how water districts are communicating with customers. I examine whether they provide information on the drought or water conservation strategies. I also examine whether and when districts started providing personalized feedback information, or social comparison information. Third, we might expect penalties to change behavior. I examine the use of penalties, collecting data on whether monetary or public penalties were issued, and if so how many over time. In addition to these policy levers, I am also examining whether drought severity and monthly precipitation affected water conservation.

To examine how policy changes affect water conservation, I have been building a month-by-month data set that integrates with existing state data. The analysis involves cross-sectional regressions, fixed effects regressions, and synthetic control regressions. Across all these approaches, the goal is to identify which policies are driving water consumption. During the first year of this grant, I undertook extensive data collection from urban water districts, conducted preliminary analyses including descriptive statistics, and gave two talks on preliminary research findings. Early results suggest that the best performing districts are relying on a more extensive range of strategies to save water: rebates, drought information, personal feedback and others. In addition, the best performing districts' average bills are two times as expensive as the worst performing districts.

**2. Research program:** California experienced a record drought that has lasted over five years and continues in some areas of the state. In April 2014 Governor Jerry Brown issued an executive order, calling on urban water districts to reduce consumption by 20% compared to their 2013 baseline. Some districts' efforts proved very successful, with savings over 50%, while others only managed 5%. Overall, 78% of reporting urban water districts had met the 20% reduction by April 2016 before the Governor lifted mandatory reductions in May 2016.

Rather than requiring specific policies and strategies to save water, California took a decentralized approach, with different districts adopting varying conservation strategies. Water districts have a number of tools at their disposal to try to change residential water consumption through demand-side management. Yet, we have very little information on which strategies worked best to change behavior and increase water conservation across California's districts or across the Western United States more broadly. This research aims to understand what strategies are most effective at driving water conservation in urban water districts. Methodologically, the analysis involves comparing across districts using cross-sectional regressions; and, comparing within districts using fixed effects regressions; and comparing behavior over time using synthetic control regressions. Across all these approaches, the goal is to identify which policies are driving water consumption.

To date, our findings involve descriptive statistics about which districts are using what kinds of strategies to try to drive water conservation. Since there is no database that lists what districts are charging for water, or what strategies they use to communicate with their customers,

these descriptive statistics are original contributions directly stemming from the grant's funding. The Tables below, which are excerpted from an ongoing working paper co-authored with a graduate student, show our findings. Overall, among the top 15 best performing districts, compared to the bottom 15 districts, very different water conservation strategies are used (Table 3). The best districts are using rebates, drought information and many other strategies to a much greater extent than the worst performing districts. In addition, the best performing districts are charging more than twice as much on average than the worst performing districts for an average water bill (Table 5). This also holds for each unit of water sold (Table 6).

Table 3: Conservation Strategies - Percent Implementation by Districts (top and bottom 15)

| Strategy | Best Performing (%) | Worst Performing (%) |
|---|---|---|
| Rebate Program | 100 | 67 |
| Drought Info | 100 | 50 |
| Pricing Structure | 75 | 50 |
| Personal Feedback | 75 | 33 |
| Info, Tips, and Tricks | 75 | 100 |
| Neighbor Comparison | 67 | 0 |
| Monetary Penalties | 60 | 33 |
| Drought Surcharge | 33 | 0 |
| Social Penalties | 33 | 0 |

Table 5: Average Bill Pricing (15 CCF Use + Service Charge)

| Districts | Min | Q1 | Mean | Q3 | Max |
|---|---|---|---|---|---|
| Best Performers | 50.38 | 69.11 | 92.20 | 116.68 | 131.26 |
| Worst Performers | 32.41 | 36.38 | 42.32 | 49.10 | 50.72 |

Table 6: Average Price per CCF Use

| Districts | Min | Q1 | Mean | Q3 | Max |
|---|---|---|---|---|---|
| Best Performers | 3.02 | 3.86 | 6.85 | 9.41 | 11.54 |
| Worst Performers | 1.00 | 1.57 | 2.15 | 2.26 | 4.27 |

**3. Information transfer/outreach program:** To date, I have presented these preliminary findings at two academic conferences (see section 7). In addition, I have scheduled a talk with a water district manager group locally for the fall. I am also looking at presenting results, when they are completed, to the Association of California Water Agencies. In addition to academic articles, we also plan to write blog posts disseminating our results. Of course, we want to have solid results before we start disseminating results fully.

# Groundwater Dynamics in Sacramento Aquifers Following California's Historic Drought

## Basic Information

| | |
|---|---|
| **Title:** | Groundwater Dynamics in Sacramento Aquifers Following California's Historic Drought |
| **Project Number:** | 2017CA374B |
| **Start Date:** | 3/1/2017 |
| **End Date:** | 2/28/2018 |
| **Funding Source:** | 104B |
| **Congressional District:** | 44 |
| **Research Category:** | Ground-water Flow and Transport |
| **Focus Categories:** | Groundwater, Water Supply, Conservation |
| **Descriptors:** | None |
| **Principal Investigators:** | Amelia Vankeuren |

## Publications


1. Loustale, Marissa; Amelia Vankeuren; Ate Visser, Residence Times in Central Valley Aquifers Recharged by Dammed Rivers, American Geophysical Union Fall Meeting, Poster, 12/12/2017, New Orleans, LA. https://agu.confex.com/agu/fm17/meetingapp.cgi/Paper/294969
2. Vankeuren, Amelia, 03/06/2018, Can California Avoid Groundwater Bankruptcy?, California State University, Sacramento's Science, Technology, Engineering, and Mathematics (STEM) Scholars Lecture. Lecture is available for public viewing at: http://csus.edu/nsm/successcenter/stem%20lecture%20series/stem%20scholars%20lectures/stem-lecture-archiv
3. Vankeuren, Amelia, 04/18/2018, Going with the Flow: Using Tracers to Protect California Groundwater, Sacramento Science Distilled, Capital Science Communicators' café science series. https://capscicomm.org/local-science-cafes/sac-science-distilled/

**Groundwater Dynamics in Sacramento Aquifers Following California's Historic Drought, Principal Investigator: Dr. Amelia Vankeuren**

## 1. Overall project summary:

During California's recent historic 5-year drought, groundwater accounted for over 60% of the state's fresh water supply. In the midst of the drought, the Sustainable Groundwater Management Act was passed, requiring high priority groundwater basins such as those around Sacramento to develop Groundwater Sustainability Plans. In order to achieve sustainability, groundwater extraction must not exceed groundwater recharge (surface water infiltration into the groundwater system). This project aims to characterize the groundwater system in east Sacramento to help quantify recharge and provide data for the input side of the groundwater sustainability equation.

Results indicate that groundwater in east Sacramento is predominantly supplied by recharge from the lower American River, though shallow wells farther from the river have significant input from local precipitation. Interestingly, recharge from the river occurs primarily during the dry summer months (May-July) rather than the period when precipitation is highest (December-April). This is due to sustained high river flows during the summer fed by releases from upstream dams to provide water for the Central Valley Project. Thus, despite the drought, flow management in the lower American River allowed for continued groundwater recharge.

These results have been presented to local groundwater professionals at the Groundwater Resources Association of California Sacramento Branch meeting, and to the public at two public lectures.

Benefits from this project include hands-on training for students in field sampling, laboratory analysis, and presentation skills. The project has also led to a new collaboration between research scientists at Lawrence Livermore National Laboratory and the CSUS Geology Department.

## 2. Research program:

The aim of this project is to determine how east Sacramento aquifers responded to California's historic 5-year drought. In the Sacramento area, decreased surface water availability and increased groundwater pumping to meet water demand is thought to have reduced recharge and caused a decline in groundwater levels, potentially altering groundwater flow paths and depleting the groundwater supply. The purpose of this project is to determine sources of recharge to groundwater, groundwater flow paths, and residence times. This information will allow us to quantify the amount of recharge from the lower American River to Sacramento area aquifers, an important data point for developing the local groundwater sustainability plan.

The field area of study is the California State University, Sacramento wellfield, which provides a remarkably detailed picture of the local groundwater system through its 16 monitoring wells. These wells offer insight into surface water-groundwater interaction with the lower American River, as they are set at various depths (20-200 ft) in two different aquifers (a shallow unconfined aquifer and a deeper confined aquifer) and at varying distances from the American River (160-2200 ft).

Samples have been collected from monitoring wells on the California State University, Sacramento (CSUS) campus and the adjacent lower American River. These samples were analyzed to determine water source via stable water isotopes ($\delta^{18}O$ and $\delta^{2}H$), groundwater age via tritium-$^{3}$helium dating and recharge temperature via dissolved noble gases.

Stable isotopes in water ($\delta^{18}O$ and $\delta^{2}H$) indicated that all wells in the confined aquifer and shallow wells close to the river (<700 ft) contained at least 80% water recharged from American River, while shallow wells farther from the river contained only 20-50% river water. Mean groundwater ages in the shallow aquifer increased with depth, and ages in the confined aquifer increased with distance from the river. All ages were relatively young, ranging from less than a year to 50 years old. Dissolved noble gas data showed wells recharged mostly by local precipitation had recharge temperatures of 16-17$^{o}$C, similar to the mean annual temperature of Sacramento. Wells recharged by river water showed lower recharge temperatures of 12-16$^{o}$C, corresponding to river temperatures during late April-July. All of these data combine to suggest that the lower American River is a primary source of water for east Sacramento aquifers. Future work will involve using the above results to quantify the amount of recharge from the lower American River and local precipitation.

**3. Information transfer/outreach program:**

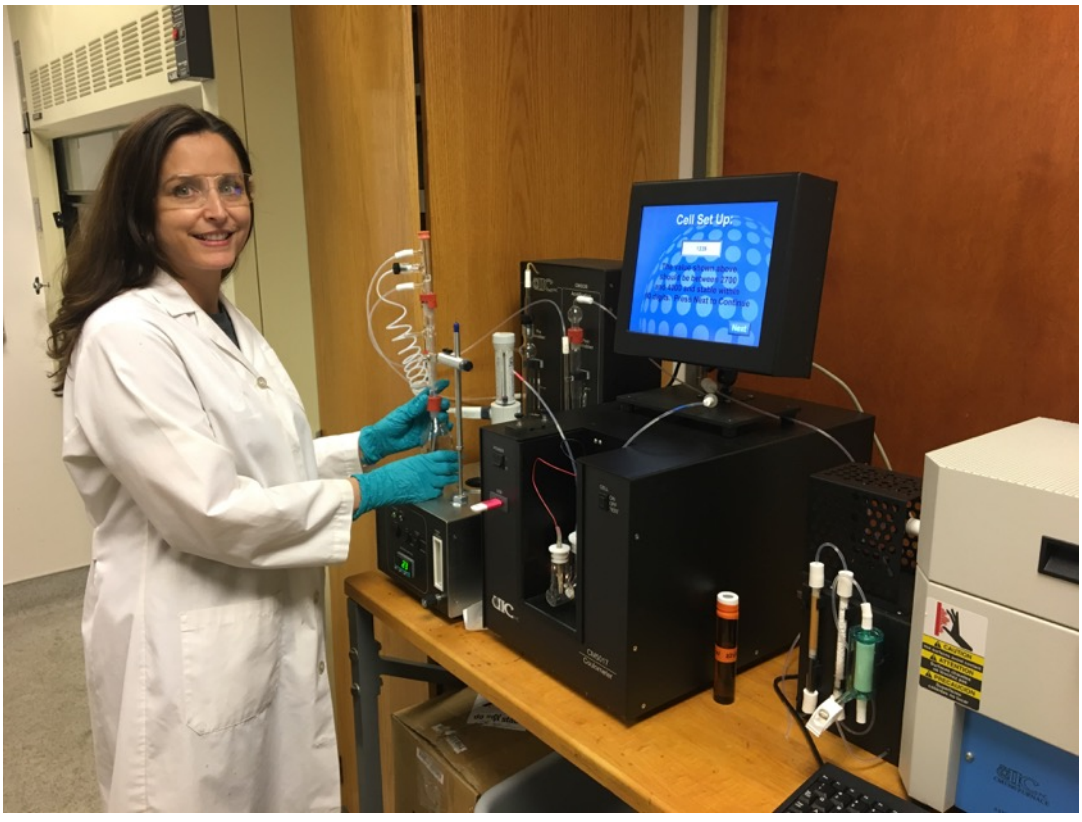
Preliminary results from this project have been presented at a local level to the public via two open lectures. The first of these was the biannual STEM Scholars Lecture at CSUS, which is attended by community members; local business and industry leaders; K-12 and community college students, faculty, and administrators; and CSUS students, faculty and alumni. The second lecture was part of Sac Science Distilled, the Sacramento Science Communicators café science series designed to bring scientists and the public together in an informal venue. Both talks were well attended, and attendees had many questions about California's groundwater.

Additional presentations were made to groundwater professionals at the Groundwater Resources Association of California Sacramento Branch meeting student night. These presentations were made by undergraduate and graduate students who had assisted in sample collection and laboratory analyses for the project.

Installing pump for groundwater sampling. From left to right: CSUS Geology undergraduate student, Dr. Ate Visser (LLNL), Dr. Amelia Vankeuren (CSUS Geology), CSUS Geology undergraduate student. Photo by Fatima Burhan (CSUS Geology).

Marissa Loustale (CSUS graduate student) collecting dissolved noble gas samples to determine recharge temperature. Photo by Amelia Vankeuren.

Amber Ginorio (CSUS Geology undergraduate student) measuring dissolved inorganic carbon in water samples in the WaterLaIR (Dr. Vankeuren's lab). Photo by Amelia Vankeuren.



# Suitability of alfalfa forage crops for winter groundwater recharge

## Basic Information

| | |
|---|---|
| **Title:** | Suitability of alfalfa forage crops for winter groundwater recharge |
| **Project Number:** | 2017CA375B |
| **Start Date:** | 3/1/2017 |
| **End Date:** | 2/28/2018 |
| **Funding Source:** | 104B |
| **Congressional District:** | 44 |
| **Research Category:** | Ground-water Flow and Transport |
| **Focus Categories:** | Groundwater, Agriculture, Water Supply |
| **Descriptors:** | None |
| **Principal Investigators:** | Helen Dahlke |

## Publications


1. Dahlke, H.E., A. Brown, S. Orloff, D. Putnam, T. O'Geen, et al., Managed winter flooding of alfalfa recharges groundwater with minimal crop damage, California Agriculture (2018) 1:11.
2. Restoring California’s ability to recharge groundwater a more cost-effective drought strategy, Website, 10/26/2017, California Economic Summit. http://caeconomy.org/reporting/entry/restoring-californias-ability-to-recharge-groundwater-a-more-cost-effecti
3. Banking on California's floodwater, Website, 10/2/2017, Frontiers in Ecology and the Environment. http://onlinelibrary.wiley.com/doi/10.1002/fee.1534/full
4. 12/6/2017, News Deeply - Water Deeply. https://www.newsdeeply.com/water/articles/2017/12/06/pioneering-practice-could-help-california-reverse-grou
5. Flooding Orchards to Replenish Groundwater A UC Experiment in Groundwater Replenishment Strategies, Video, 1/15/2018. https://www.uctv.tv/sustainable-cal/search-details.aspx?showID=32526
6. Potential of Using Agricultural Fields for Groundwater Recharge: Soil Water Balance, Crop Suitability and Surface Water Availability, Invited Speaker, engineers, agency staff, California Groundwater Resources Agency, Northern Branch meeting, Chico, CA, 5/4/2017, 35 Attendees.
7. Managed Groundwater Recharge to Support Sustainable Water Management Forum, Invited Speaker, agency staff, water managers, practitioners, scientists, Sacramento Convention Center, 11/8/2017, 200 Attendees. https://secure.cdfa.ca.gov/egov/groundwater/

**Progress Report for California Institute for Water Resources Project Support**

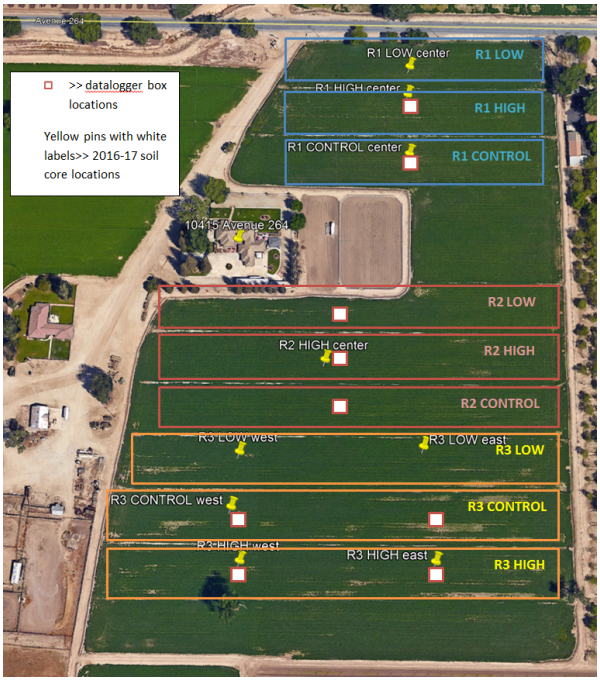
**Suitability of alfalfa forage crops for winter groundwater recharge**
**Investigators: Helen Dahlke, Nicholas Clark, Steve Orloff, Dan Putnam**

## 1. Overall project summary/statement:

The main goal of this research was to conduct field studies over two years to increase knowledge of the response of alfalfa forage crops to winter water application for groundwater recharge. The project planned to conduct replicated field experiments on two commercial alfalfa fields (provided by volunteering landowners) and one field at the Kearney Agricultural Research and Education Center to test the effect of modest and high amounts of winter water application on growing season alfalfa yield on different soils and under different climate conditions. The research also aimed to assess the effect of fall dormancy rating on alfalfa response and how winter water application affects growing season water balance and irrigation demand. Test sites will be instrumented with several soil moisture sensor profiles to quantify the amount of water going to deep percolation during winter recharge and to estimate potential benefits of on-farm recharge for the growing season irrigation demand. Crop response (e.g. total yield, wet and dry matter, weeds, and alfalfa density) will be determined in each treatment area and collected data will be used to estimate the risks, costs and benefits of winter on-farm recharge on alfalfa and the need for economic incentive tools. To date, one field site from a volunteering landowner located north of Tulare, CA was instrumented for a replicated study, however, the site did not receive winter water for recharge. The landowner of a second site that was identified in the Big Valley, northern California retracted his collaboration after co-PI Steve Orloff passed away. Despite these experimental setbacks several outreach and education efforts have been completed where the PI mainly presented results from a preliminary study. In the upcoming winter (2018/19) we hope to complete the planned experiments and continue our outreach efforts.

## 2. Research program:

In summer of 2017, volunteering landowners were contacted by the PI and Steve Orloff and two potential sites (one located north of Tulare, CA, the other was located in the Big Valley, Modoc County) were identified. The Tulare site was instrumented, cored to extract soil cores for laboratory analysis, and prepared for winter flooding. The Tulare site consists of a 4-year old alfalfa stand on a 22 acre field that is divided into 12 individually flood irrigated checks. Nine sensor profiles were installed across all checks (Fig. 1). The site is characterized by a Tagus loam with a SAGBI rating of good. The site was instrumented with 10 soil moisture and soil EC profiles. At each location one Decagon GS-1 (volumetric water content, temperature) and one Decagon GS-3 (volumetric water content, temperature,



electrical conductivity) were installed at 15 and 45 cm depth. Data was recorded at 10 min intervals. Water for groundwater recharge was supposed to be applied in the winter of 2017/18 but because of the below-average precipitation the local water district (Tulare Irrigation District) was not able to deliver surface water to the site.
A second landowner was identified in the Big Valley, Modoc County on less suitable soil (Patburn Clay loam, SAGBI rating moderately poor) with alfalfa varieties with different fall dormancy ratings. However, the landowner retracted his collaboration after Steve Orloff passed away in October 2017.
For the upcoming winter we plan to find a second private landowner to conduct on-farm recharge experiments and we hope to conduct one set of experiments at the Kearney Center, which so far did not allow access to their conventional alfalfa due to a conflict with a nematode research project.

**3. Information transfer/outreach program:**

The topic of winter groundwater recharge on farmland has received a lot of media attention.

# Development of a field-based approach to estimate soil N mineralization for field-specific fertilizer N adjustments

## Basic Information

| | |
|---|---|
| **Title:** | Development of a field-based approach to estimate soil N mineralization for field-specific fertilizer N adjustments |
| **Project Number:** | 2017CA376B |
| **Start Date:** | 3/1/2017 |
| **End Date:** | 2/28/2018 |
| **Funding Source:** | 104B |
| **Congressional District:** | 44 |
| **Research Category:** | Biological Sciences |
| **Focus Categories:** | Nitrate Contamination, Geochemical Processes, Agriculture |
| **Descriptors:** | None |
| **Principal Investigators:** | Daniel Geisseler |

## Publications


1. Miller, Kenneth MSc thesis entitled "Predicting Nitrogen Mineralization in California Agroecosystems" Submitted on 03/28/2018
2. Miller, K., Geisseler, D., 2017. Nitrogen Mineralization Potential in California Agricultural Soils. 2017 Proceedings of the California Plant and Soil Conference, 134. http://calasa.ucdavis.edu/files/257056.pdf
3. Miller, K., Geisseler, D., 2018. Predicting Nitrogen Mineralization in California Agroecosystems. 2018 Proceedings of the California Plant and Soil Conference, 134. http://calasa.ucdavis.edu/files/278374.pdf
4. Geisseler, D., 2017. Estimating soil nitrogen mineralization for fertilizer adjustments - Preliminary project report. Intermountain REC news: http://ucanr.edu/blogs/blogcore/postdetail.cfm?postnum=23500
5. Leinfelder Miles, M., Geisseler, D., 2017. Nitrogen Mineralization in Organic and Mineral Soils. Delta Blog: http://ucanr.edu/blogs/blogcore/postdetail.cfm?postnum=23911
6. Geisseler, D., November 14, 2016. Decision Support Tools for Nutrient Management in Processing Tomatoes. Oral presentation. California Tomato Conference, Napa, CA.
7. Miller, K.S. and Geisseler, D., January 31, 2017. Nitrogen Mineralization Potential in California Agricultural Soils. Poster. California Plant and Soil Conference, Fresno, CA.
8. Miller, K.S. and Geisseler, D., February 6, 2018. Predicting Nitrogen Mineralization in California Agroecosystems. Poster. California Plant and Soil Conference, Fresno, CA.

**Progress Report for California Institute for Water Resources Project Support**

# Development of a field-based approach to estimate soil N mineralization for field-specific fertilizer N adjustments

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*Nicholas Clark,* UCCE Farm Advisor, Kings, Tulare, & Fresno Counties
*Gene Miyao*, UCCE Farm Advisor, Yolo, Solano & Sacramento Counties
*Michelle Leinfelder-Miles*, UCCE Farm Advisor, San Joaquin County
*Richard Smith*, UCCE Farm Advisor Monterey County
*Rob Wilson*, Intermountain REC Director, UCCE Farm Advisor

## 1. Overall project summary/statement:

Due to high groundwater nitrate concentrations, California growers are facing increasing regulatory pressure to improve nitrogen (N) use efficiency in crop production to reduce nitrate leaching. To maintain high yield levels, growers need accurate estimates of crop available N that doesn't come from fertilizer so that they can adjust fertilizer application rates with confidence. This project aims to determine N mineralization rates in a variety of agricultural soils from California. The data shall be used to develop a simple tool that allows estimating field-specific N mineralization rates.

In spring 2016 and 2017, we collected undisturbed soil cores from 57 fields under annual crops located in the northern half of California (Figure 1). The soil organic matter (SOM) contents in these soils differed widely, ranging from 1-23%. The soil cores were incubated at optimal moisture content and different temperatures for 10 weeks. A number of analyses were performed to characterize the soils. A greenhouse trial was also included in the study.

The results show that N mineralization increases exponentially within the investigated temperature range of 5-25 °C. The temperature response differed little across regions.

For soils with a high soil organic matter content, a model based on total soil C and N, particulate organic C and N and sand content was best in predicting N mineralization rates. For soils with a low SOM content, FDA hydrolysis, a measure for soil enzyme activity, and pyrophsphate extractable Fe were the best predictors. While the model predicted N mineralization very well in soils with a higher SOM content, it was less successful in low SOM soils, where interactions with soil minerals and cropping history may strongly affect N mineralization rates.

Preliminary results from this study were presented at numerous meetings and conferences in California.

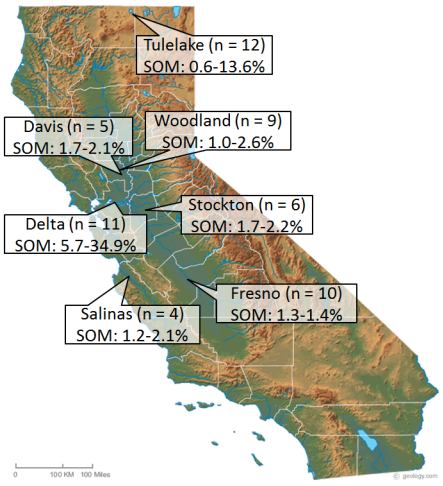


**Figure 1:** Location and range in soil organic matter content (SOM) of the sites sampled in spring 2016 and 2017.

## 2. Research program:

In collaboration with local farm advisors, we selected field sites in different regions of the state with widely different soils and climatic conditions (Figure 1). Undisturbed soil cores (2-in. diameter, 6 in. long) were collected

from a depth of 3-9 inches, representing the top foot of the profile. Samples from the soil surrounding the cores were taken from the same layer at the same time. These samples were sieved and analyzed for a wide range of soil properties (Table 1). The soil cores were incubated for 10 weeks at different temperatures (5, 15 and 25 °C) and at an optimal moisture content of 60% water filled pore space to determine N mineralization rates and their temperature response. In addition, a pot trial was carried out in the greenhouse. The samples represented a wide range of soil properties (Table 1).

**Table 1:** Select properties of the samples taken in the different regions.

| **Soil property** | **Region** | | | | | |
|---|---|---|---|---|---|---|
| | **San Joaquin Valley** | **Sacramento Valley** | **Salinas** | **Delta** | **Tulelake** | **Others** [1)] |
| Number of sites | 16 | 14 | 4 | 11 | 10 | 2 |
| Bulk density ($g\ cm^{-3}$) | 1.19 (1.1 - 1.31) | 1.28 (1.17 - 1.48) | 1.45 (1.32 - 1.68) | 0.84 (0.63 - 1.33) | 0.71 (0.43 - 0.92) | 1.36 (1.34 - 1.37) |
| Total C ($g\ kg^{-1}$) | 10.1 (7.3 - 12.8) | 11.1 (6 - 15.3) | 9.2 (6.7 - 12) | 90.4 (33 - 198.4) | 49.8 (31.4 - 78.6) | 7.4 (6 - 8.8) |
| Total N ($g\ kg^{-1}$) | 1.16 (0.85 - 1.41) | 1.18 (0.69 - 1.56) | 1.12 (0.83 - 1.39) | 6.22 (2.71 - 12.48) | 4.65 (2.92 - 7.16) | 0.71 (0.65 - 0.77) |
| Particulate organic N ($g\ kg^{-1}$) | 0.14 (0.05 - 0.21) | 0.16 (0.08 - 0.28) | 0.09 (0.05 - 0.12) | 1.62 (0.15 - 5.25) | 0.89 (0.35 - 1.91) | 0.15 (0.12 - 0.19) |
| Particulate organic C ($g\ kg^{-1}$) | 1.72 (0.78 - 2.55) | 1.85 (1.01 - 3.1) | 1.09 (0.56 – 1.76) | 27.41 (2.32 - 90.87) | 10.70 (4.64 - 25.13) | 2.86 (1.8 - 3.93) |
| pH | 7.58 (7.17 - 8.06) | 7.68 (7.2 - 8.08) | 7.46 (7.24 - 7.65) | 6.54 (5.9 - 7.27) | 7.07 (6.19 - 7.65) | 6.54 (5.57 - 7.5) |
| Electrical conductivity ($mS\ m^{-1}$) | 90.3 (14.4 - 250) | 15.2 (7.8 - 27.8) | 20.0 (12.3 - 24.3) | 29.4 (12.9 - 63) | 42.1 (14.3 - 97.2) | 12.3 (11.7 - 12.8) |
| Sand (%) | 23.0 (8.7 - 35) | 26.4 (5.5 - 64.9) | 46.8 (38.5 - 60.3) | 9.6 (0.9 - 18.9) | 7.6 (2.3 - 16.1) | 83.2 (80.2 - 86.1) |
| Clay (%) | 36.6 (20 - 49.2) | 29.4 (10.9 - 58.8) | 16.0 (11.9 - 21.5) | 43.1 (32.2 - 61.5) | 56.2 (49.4 - 68.6) | 8.6 (8.4 - 8.8) |
| Permanganese oxidisable C ($mg\ kg^{-1}$) | 345 (259 - 477) | 369 (262 - 460) | 333 (210 - 477) | 1966 (775 - 3578) | 776 (245 - 1564) | 217 (192 - 241) |
| FDA hydrolysis ($mg\ kg^{-1}\ h^{-1}$) | 16.8 (9.8 - 30) | 14.8 (4.8 - 33.6) | 7.5 (3.4 - 10.3) | 40.1 (25.1 - 68.8) | 34.0 (20.4 - 76.7) | 9.3 (9.1 - 9.5) |
| Pyrophosphate extr. iron ($mg\ kg^{-1}$) | 88 (34 - 154) | 168 (101 - 276) | 173 (136 - 261) | 4236 (832 - 7623) | 546 (179 - 2076) | 135 (56 - 215) |
| Dithionite extr. iron ($g\ kg^{-1}$) | 10.80 (7.75 - 13.46) | 14.64 (10.42 - 17.65) | 7.18 (6.32 - 8.16) | 9.77 (7.39 - 12.32) | 3.14 (2.54 - 4.17) | 2.63 (2.25- 3.01) |

[1)] These are two soils sampled in the Tulelake area outside the basin

The amount of N mineralized in undisturbed soil cores incubated at 25 °C for 10 weeks varied considerably (Figure 2). Using multiple linear regression, we determined the best model to predict net N mineralization based on soil properties measured. For soils with a high soil organic matter content from the Delta and Tulelake basin, the amount of N mineralized during the 10-week incubation at 25 °C was best estimated based on total soil C and N, particulate organic C and N and sand content (Figure 3). For soils with a low SOM content, FDA hydrolysis, a measure for soil enzyme activity, and pyrophsphate extractable Fe were the best predictors. The model was less

accurate in low SOM soils, where interactions with soil minerals and cropping history may strongly affect N mineralization rates.

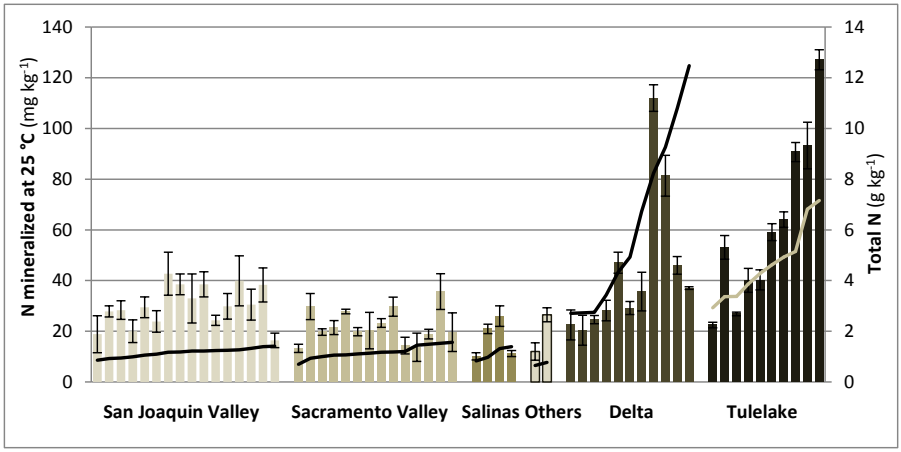


**Figure 2:** Nitrogen mineralization in undisturbed soil cores. The cores were incubated at optimal moisture content at 25 °C for 70 days. Within the regions the sites are arranged in order of increasing total soil N. Error bars represent standard error (n = 3).

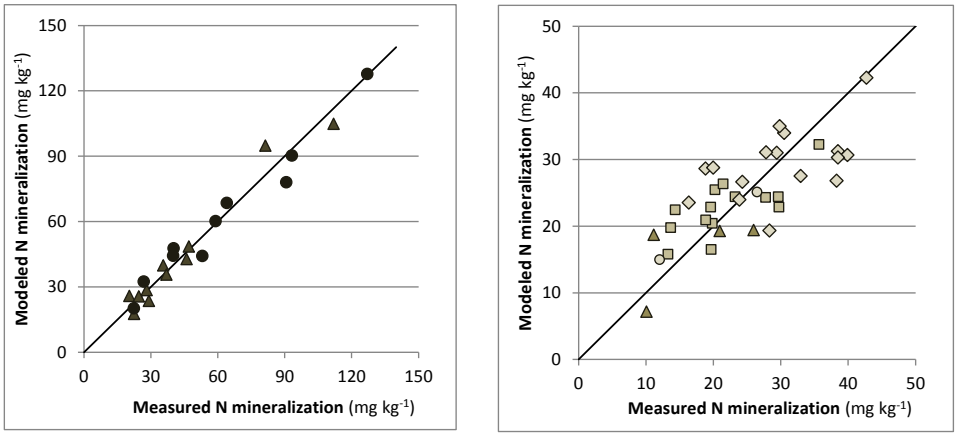


**Figure 3:** Comparison between measured and modeled N mineralization. Left panel, soils with a high SOM content (adjusted $R^2$: 0.95); right panel, soils with a low SOM content (adjusted $R^2$: 0.55).

One goal of the project was to determine N mineralization in the field by taking pre-plant soil samples twice in spring, with the two sampling events being approximately 6-8 weeks apart. In both years, 2016 and 2017, relatively late rainfalls prevented us from taking early samples. As soon as the soils were dry enough, growers started preparing the fields, so that it was not possible to take samples twice pre-plant several weeks apart. Based on this experience, this approach of determining N mineralization in the field is not practical.

## 3. Information transfer/outreach program:

The preliminary results from this study were incorporated into oral presentations held at nine meetings and conferences. The audience at these outreach events included growers, crop advisors and scientists. In addition, two posters were presented at the California Plant and Soil Conference.

In collaboration with farm advisors, summaries of the first-year results were also published online on their blogs.

# Numerical Modeling of Local Intense Precipitation Processes

## Basic Information

| | |
|---|---|
| **Title:** | Numerical Modeling of Local Intense Precipitation Processes |
| **Project Number:** | 2017CA379S |
| **USGS Grant Number:** | G15AP00045 |
| **Sponsoring Agency:** | Nuclear Regulator Commission |
| **Start Date:** | 1/4/2014 |
| **End Date:** | 8/1/2018 |
| **Funding Source:** | 104S |
| **Congressional District:** | None |
| **Research Category:** | None |
| **Focus Categories:** | |
| **Descriptors:** | None |
| **Principal Investigators:** | |

## Publications


1. Mure-Ravaud, M., Ishida, K., Kavvas, M. L., Yegorova, E. and Kanney, J., 2017. Reconstruction of the Precipitation Fields of Intense Historical Tropical Cyclones with the Weather Research and Forecasting (WRF) Model in the Simulation Mode. In Proceedings of the World Environmental & Water Resources Congress (EWRI) 2017.
2. Mure-Ravaud, M., Ishida, K., Kavvas, M. L., Yegorova, E. and Kanney, J., 2017.Reconstruction of the Precipitation Field in a Training Line/Adjoining Stratiform Mesoscale Convective System in the Simulation Mode with the Weather Research and Forecasting (WRF) Model. In Proceedings of the World Environmental & Water Resources Congress (EWRI) 2017.
3. Mure-Ravaud, M., Dib, A., Kavvas, M. L., and Yegorova, E., 2018, Maximization of the precipitation from tropical cyclones over a target area through physically based storm transposition, Manuscript under review for journal Hydrol. Earth Syst. Sci, MS No.: hess-2017-665.
4. Kavvas, M. L., Dib, A., Mure-Ravaud, M., December 4-5, 2017. Numerical Simulation of Local Intense Precipitation. Presentation given at the 3rd Annual U.S.NRC Probabilistic Flood Hazard Assessment Research Workshop at the U.S. NRC Headquarters in Rockville, Maryland.
5. Mure-Ravaud, M., Ishida, K., Kavvas, M. L., Yegorova, E., Kanney, J. May 25, 2017. Reconstruction of the precipitation field in a Training Line/Adjoining Stratiform Mesoscale Convective System in the simulation mode with the Weather Research and Forecasting (WRF) model. Oral presentation given at the World Environmental & Water Resources Congress at Sacramento, California, May 21-25, 2017.
6. Mure-Ravaud, M., Ishida, K., Kavvas, M. L., Yegorova, E., Kanney, J. May 23, 2017. Reconstruction of the precipitation fields of intense historical Tropical Cyclones with the Weather Research and Forecasting (WRF) model in the simulation mode. Poster presentation given at the World Environmental & Water Resources Congress at Sacramento, California, May 21-25, 2017.
7. Kavvas, M. L., Ishida, K., Mure-Ravaud, M. January 23-25, 2017. Numerical Simulation of Local Intense Precipitation. Presentation given at the 2nd Annual U.S.NRC Probabilistic Flood Hazard Assessment Research Workshop at U.S. NRC Headquarters Rockville, Maryland.

# Progress Report for California Institute for Water Resources Project Support

Project title: Numerical Modeling of Local Intense Precipitation Processes
Principal Investigator: M. Levent Kavvas, Dept. of Civil & Env. Engineering, UC Davis

## 1. Overall project summary/statement

Tropical Cyclones (TCs) and Mesoscale Convective Systems (MCSs) are recognized for their ability to generate intense precipitation that may create disastrous floods over the United States. We assess the suitability of the Weather Research and Forecasting (WRF) model for simulating local intense precipitation processes within intense historical TCs and MCSs, as well as its suitability to serve as a test bed for storm transposition techniques.

Our findings reveal that under an appropriate choice of the model's options and initial/boundary conditions, the WRF model can simulate these extreme weather systems quite well, while satisfactorily reproducing the location, intensity, and texture of the intense precipitation fields. Moreover, we were able to successfully perform the transposition of four TCs and one MCS over their respective target areas through physically based methods that utilize the WRF model. Through such transposition, we were able to determine the maximized precipitation field that the respective storms could have physically produced over the target areas. For example, the observed and maximized precipitation fields for Hurricane Isaac and for the July 18, 2007 MCS are shown in Figs. 1 and 2. Such maximization mechanisms can be utilized in the future to simulate extreme precipitation over any selected location within the United States, and to estimate extreme floods over the selected location for design and operation purposes.

We have presented our results thus far at the 2017 World Environmental and Water Resources Congress in Sacramento, and at the U.S. NRC 3nd Annual Probabilistic Flood Hazard Assessment Research Workshop at Rockville, Maryland.

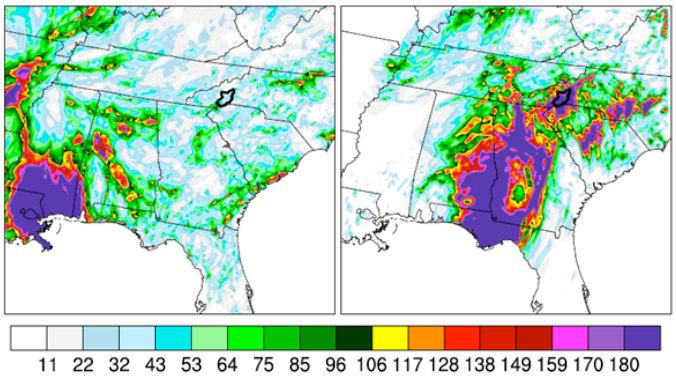


Figure 1 – Observed (left) and maximized (right) accumulated precipitation fields for Hurricane Isaac (2012), computed from 08/28 12h to 09/04 12h.

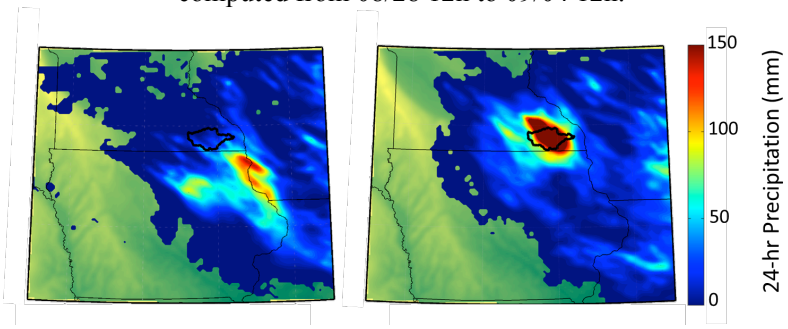


Figure 2 – Observed (left) and maximized (right) accumulated precipitation fields for the July 18, 2007 MCS, computed from 07/17 11h to 07/18 11h.

## 2. Research program

The objective of this project is to assess the suitability of a regional numerical weather model in simulating local intense precipitation processes, and then to investigate the physical mechanisms of storm systems that

lead to extreme precipitation. Tropical Cyclones (TCs) and Mesoscale Convective Systems (MCSs) are such storm systems that are recognized for their ability to generate intense precipitation which can create disastrous floods.

In this project, we have assessed the suitability of the Weather Research and Forecasting (WRF) model to simulate local intense precipitation processes within intense historical TCs and MCSs which have affected the United States. The NCEP Stage-IV precipitation dataset was used to select the severe storm systems that we simulated in this project, which spanned the period from 2002 to the present. The initial and boundary conditions for our simulations were obtained from the Climate Forecast System Reanalysis (CFSR) dataset.

For the simulations of the MCSs, the model's simulation nested domains were set up over a region in the Midwest so that the innermost domain covered the severe precipitation areas caused by these storm systems. However, several sets of nested domains were prepared for the simulations of the TCs because of the diversity in the paths of these systems. With these sets of nested domains, we configured the WRF model to obtain the best results for the simulation of each of the selected severe MCSs and TCs with respect to the simulated and observed precipitation fields.

We compared the simulation results with observations from the Stage-IV dataset. On the one hand, the simulation results were evaluated by means of several goodness-of-fit statistics: the relative error for the simulation inner-domain total precipitation, the overlap percentage between the simulated and observed fields, and the precipitation field area ratio for several precipitation thresholds. On the other hand, the simulated and observed precipitation fields were plotted to visually appreciate the similarities and differences in the fields' texture and structure. From this comparison, we found that under an appropriate choice of the model's options and initial/boundary conditions, the WRF model managed to reconstruct in the simulation mode (i.e., without any nudging or data assimilation) the precipitation fields of these severe historical TCs and MCSs.

We also worked on developing a physically based storm transposition method for the transposition of TCs. The objective of this method was to find the amount of shift which maximizes the precipitation depth over a given target area. The transposition method uses the WRF model to numerically simulate the transposed TC and its precipitation field, as such it has the fundamental advantage of conserving the mass, momentum, and energy in the system. This method is based on the shifting of the initial vortex of the TC at the simulation start date. The transposition method was applied to four hurricanes that had spawned torrential precipitation in the United States, and the drainage basin of the city of Asheville, NC was selected as the target. It was observed that the precipitation fields changed in both structure and intensity after transposition. The convergence of the vertically integrated vapor transport (IVT) was found to play a central role in the generation of intense precipitation in these hurricanes.

Moreover, we also utilized a physically based method for the transposition of one MCS by using the WRF model. This method involved shifting the initial and boundary conditions of the WRF model domains. The objective of this exercise was to find the amount of shift which maximized the precipitation depth of a MCS over a target watershed. The target watershed chosen for the MCS transposition was Root River above Houston, located in the southeastern part of Minnesota. Similar to the transposition of TCs, this transposition exercise showed that such a physically based transposition method does not simply transpose the observed precipitation field over the target watershed. In fact, in addition to a higher precipitation depth caused over the target watershed, the transposition also caused the shape and intensity of the MCS to change.

**3. Information transfer/outreach program**

The project team participated in the 2017 World Environmental and Water Resources Congress in Sacramento, and in the U.S. NRC 3$^{nd}$ Annual Probabilistic Flood Hazard Assessment Research Workshop at Rockville, Maryland in order to present the project's results to date.

# The Use of NMR Logging Measurements to Estimate Hydraulic Conductivity in Glacial Aquifers

## Basic Information

| | |
|---|---|
| **Title:** | The Use of NMR Logging Measurements to Estimate Hydraulic Conductivity in Glacial Aquifers |
| **Project Number:** | 2017CA380G |
| **USGS Grant Number:** | G17AP00134 |
| **Start Date:** | 9/8/2017 |
| **End Date:** | 9/7/2020 |
| **Funding Source:** | 104G |
| **Congressional District:** | None |
| **Research Category:** | None |
| **Focus Categories:** | |
| **Descriptors:** | None |
| **Principal Investigators:** | |

## Publication

1. Kendrick A; R Knight, 2018, Quantifying porosity domains in geological materials using displacement-T2 data, "in" The 14th International Bologna Conference on Magnetic Resonance in Porous Media, Groupement Ampere, Gainesville, FL, 45

**Progress Report for California Institute for Water Resources Projects**

# The Use of NMR Logging Measurements to Estimate Hydraulic Conductivity in Glacial Aquifers

**Progress Report for Time Period 18 September 2017 – 1 March 2018**

**Principal Investigator:**
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**Co-Principal Investigators:**
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Carole Johnson, Hydrologist, USGS, Office of Groundwater, Branch of Geophysics, cjohnson@usgs.gov, 860-487-7402 x17
Gaisheng Liu, Associate Scientist, Geohydrology Section, Kansas Geological Survey, University of Kansas, gliu@kgs.ku.edu, 785-864-2115

## Overall project summary/statement:

The Glacial Aquifer System is an important national water supply source, delivering water to 41 million people. Given the extensive use of the Glacial Aquifer System for drinking water and public supply, there is a need to characterize its hydrogeologic properties to provide a scientific basis for groundwater management. It is widely recognized within the USGS and elsewhere that characterization of the Glacial Aquifer System is difficult using traditional approaches. Yet, important assessments cannot be performed reliably without this characterization.

The focus of this research is the use of nuclear magnetic resonance (NMR) logging as a means of determining hydraulic conductivity ($K$) in glacial aquifers. Compared to other field approaches, NMR logging has important advantages: it can be performed rapidly and allows for high-resolution characterization along a vertical profile, does not require that the well be screened over the test interval, and should not be affected by insufficient well development. Based on the extensive testing and demonstration of this tool, we can conclude that we now have a quick, reliable, and cost-effective way to conduct NMR logging for groundwater applications. The challenge to be addressed here is that of transforming the NMR parameters acquired through NMR logging to accurate estimates of $K$. This project involves field, laboratory and numerical studies to determine the optimal way to use NMR logging measurements to determine $K$ in glacial aquifers.

The work conducted during the first six months of this project has involved the design and start of the laboratory experiments, and the planning for the fieldwork, conducted in early June. NMR flow experiments were successfully used to quantify the flowing portion of the pore space in sorted sand samples. Two field sites within the Glacial Aquifer System in central Wisconsin were selected and data collection planned to evaluate the NMR logging tools.

## 2. Research program:

Hydraulic conductivity is an essential parameter for groundwater management that describes how easily water can flow through the subsurface. Despite its importance, hydraulic conductivity is difficult to quantify without extensive pumping tests. Geophysical well logging tools such as nuclear magnetic resonance (NMR) can measure properties of the subsurface that are proxies for hydraulic conductivity ($K$). With the appropriate calibration, these logging tools can quantify subsurface variations in $K$ without the need for time consuming pumping tests. We will use both laboratory and field measurements of $K$ to investigate the link between material properties and $K$.

Most models connecting NMR to $K$ depend on measurements of the transverse relaxation time, $T_2$, which is considered a proxy for the pore size distribution under certain assumptions. At the pore scale, not all pores, or portions of the $T_2$ distribution, form the connected pathways that transport water through the material. Understanding this variability in pore scale fluid flow with NMR could improve our ability to estimate $K$ from $T_2$.

To quantify the portion of the $T_2$ distribution responsible for fluid flow, we implemented a pulsed gradient spin-echo sequence on a low-field (2 MHz) Rock Core Analyzer (RCA) NMR system in the lab. Using this sequence and a specially designed core holder, we measured fluid flow through a series of sorted sand samples. For layered sand samples, we find that we can clearly distinguish fluid flow through pores with separate $T_2$ values. To test our ability to resolve a contrast between flowing and stagnant water in different regions of the pore space, we performed experiments on a naturally occurring zeolite. Zeolites are a geological material containing both large millimeter-scale pores and small micrometer-scale pores. With our NMR flow experiments we are able to identify a clear transition between flow in the large pores, and stagnant water in the small pores. This work will enable us to identify the connected, flowing portion of the pore space in our core samples from the field portion of the project. We will investigate whether these measurements could provide additional information that will improve our estimates of $K$ from the laboratory samples in comparison to the other geophysical methods used in this study.

To investigate the use of NMR logging as a means of determining $K$ in glacial aquifers, two sites in central Wisconsin were chosen for a 9-day field campaign using multiple geophysical logging tools. A series of logging tools were selected to characterize the subsurface at each location and provide information that could be used to evaluate the NMR measurements of $K$. A direct push system was selected to install two wells 30 feet apart at each site. At each of these locations, the system will record an estimate of $K$ and the formation electrical conductivity (EC) as a function of depth using the hydraulic profiling tool (HPT). Once the wells are installed, a natural gamma, EC, and NMR log will be collected downhole. Adjacent to each well, the same direct push system will be used to collect high-resolution $K$ measurements as a function of depth using a direct push permeameter (DPP). These co-located logging measurements will be used to calibrate the empirical models used to relate NMR logging measurements to $K$. At one of the sites, core samples of the subsurface will be collected from the same formation measured by the logging tools. Samples of the pore water from the core will be collected and stored anaerobically in the field. These water samples will be analyzed in the lab to determine the iron and manganese speciation as well as trace metals present in the pore water. Knowing the precise groundwater chemistry could help explain potential variations seen between laboratory and field NMR measurements. Combining the laboratory experiments and planned field campaign will allow us to study the link between NMR, geological parameters, and $K$ across multiple scales.

**3. Information transfer/outreach program:**

None to date

# Information Transfer Program Introduction

None.

# USGS Summer Intern Program

None.

| Student Support | | | | | |
|---|---|---|---|---|---|
| **Category** | **Section 104 Base Grant** | **Section 104 NCGP Award** | **NIWR-USGS Internship** | **Supplemental Awards** | **Total** |
| **Undergraduate** | 4 | 0 | 0 | 1 | 5 |
| **Masters** | 4 | 0 | 0 | 1 | 5 |
| **Ph.D.** | 7 | 0 | 0 | 1 | 8 |
| **Post-Doc.** | 5 | 1 | 0 | 0 | 6 |
| **Total** | 20 | 1 | 0 | 3 | 24 |

# Notable Awards and Achievements

2017CA369B, Eric Palkovacs: • M. Sabal awarded 1st place for student oral presentations at 2018 AFS CalNeva conference • M. Sabal awarded the Delta Science Fellowship for continued support to execute and expand this project • Submitted manuscript for publication

2017CA375B, Helen Dahlke: The project has received a lot of media attention over the past 2-3 years. One effect of this research on groundwater recharge is that the California Department of Water Resources is currently considering the potential for using floodwater for managed groundwater recharge (Flood-MAR) on farmland and working landscapes for flood protection, drought preparedness, aquifer remediation, and ecosystem restoration.

2016CA365B Amanda Banet: A presentation of this research by graduate student N. Balfour won first place at the California State University, Chico's College of Natural Sciences Research Symposium.

2017CA374B, Amelia Vankeuren: A masters student spent Summer 2017 analyzing samples at the Lawrence Livermore National Laboratory (LLNL) supported by a Glenn T. Seaborg Institute Summer Internship in Nuclear Forensics and Radiochemistry

2016CA364B, Andrew Gray: A new collaborative investigation into the carbon dynamics of chaparral landscapes involving the PI and Associate Professor Jeff Hatten, Oregon State University Department of Forestry has been made possible by the sediment sampling efforts involved in this study. Another new collaborative investigation has also begun with Dr. Kingsley Odigie, a geochemist specializing in heavy metal stable isotopes.

2017CA371B Amir Hagverdi: The research team was awarded two additional extramural funds to expand the work initiated using this seed grant.

2017CA379S, Levvent Kavvas: The project team successfully reconstructed the precipitation field in 14 MCSs whereas these systems are very complicated and difficult to simulate. Besides, the project team performed the physically based storm transposition of four T

2017CA380G, Rosemary Knight: Alex Kendrick, the PhD student supported by this work, received an ARCS (Achievement Rewards for College Scientists) Foundation fellowship for 2018-2019. This award recognizes students “who have a record of past achievement and show exceptional promise of making a significant contribution to the scientific and technological strength of the nation”.